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Assessment of Crew Time for Maintenance and Repair Activities for Lunar Surface Missions

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Assessment of Crew Time for Maintenance and Repair Activities

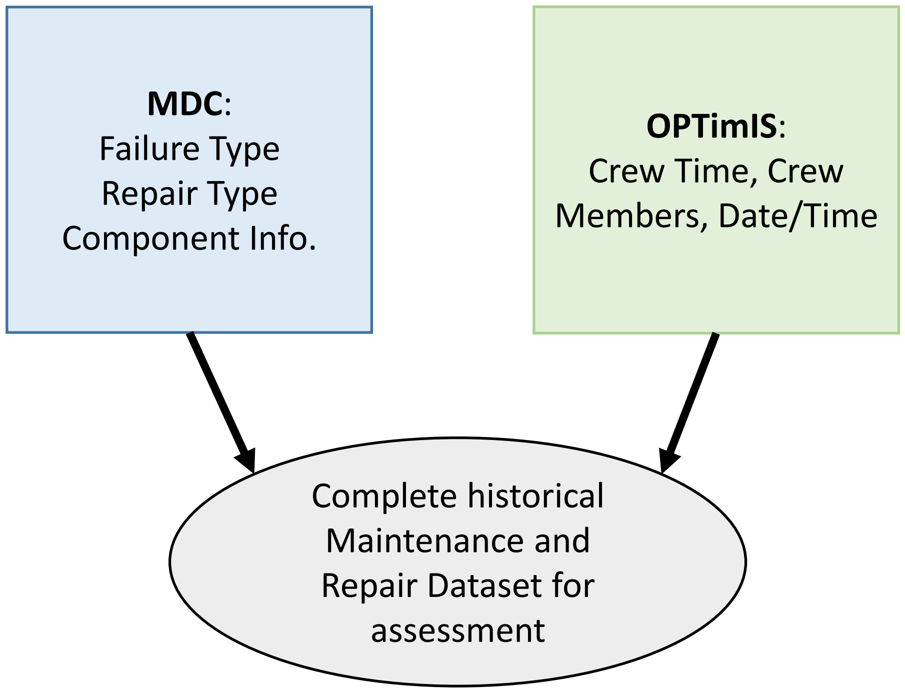
- As technology progresses and human spaceflight missions become more innovative and complex, the uncertainty of required maintenance and repairs to support sustained human space missions increases
- The International Space Station (ISS) provides the largest set of maintenance and repair data
- A methodology was developed to assess and analyze historical ISS maintenance and repair data to better predict required crew time on maintenance and repair activities
- The model will allow analysts to develop a realistic crew schedule that includes required liens

Definitions

- **Failure**
  - Any situation or condition that prohibits the component from functioning at nominal performance
- **Event Type**
  - Preventive (Scheduled)
    - A maintenance event that has been preplanned or scheduled prior to the start of the mission in order to maintain the health of a system or subsystem
  - Corrective
    - A crew action in response to any anomaly within an Orbital Replacement Unit (ORU) resulting in required crew time
- **Action Type**
  - Maintenance
    - Scheduled maintenance actions for system health
  - Repair and Replace (R&R)
    - Following assessment or repairs, the component is replaced by a spare
  - Repair (non-R&R)
    - The component is repaired on-board and is continued to be used

ISS Data Sources and Collection

- **OPTimIS**
  - NASA's ISS crew's planning and schedule system, containing all previous and planned future crew activity onboard
  - A data processing tool was developed to process raw OPTimIS text data and categorize it based on activity
- **MDC**
  - Contains details on each maintenance and repair actions conducted onboard ISS
  - Failure type, maintenance type, component data, and more
- **Repair events are tied to probabilistic factors**
- **When observing historical maintenance and repair data for predictive measures, it is vital to know the event type and the action type**
- ***An assessment of both OPTimIS crew time data and MDC maintenance and repair data provides a complete picture of historical ISS maintenance and repair events***



Data Conditioning and Analysis

- **Maintenance and repair data is collected and organized, starting with component category**
- **Component categories were created based on component function and complexity**
- **Categorizing increases size of data pool and provides opportunity to analyze data-deficient components**
  - Some components are exceptions to categorizing
- **Historical maintenance and repair data is separated within component category by failure type and maintenance type**
  - Corrective repairs are separated from preventive maintenance events
  - The corrective failures are divided into R&R's and non-R&R's

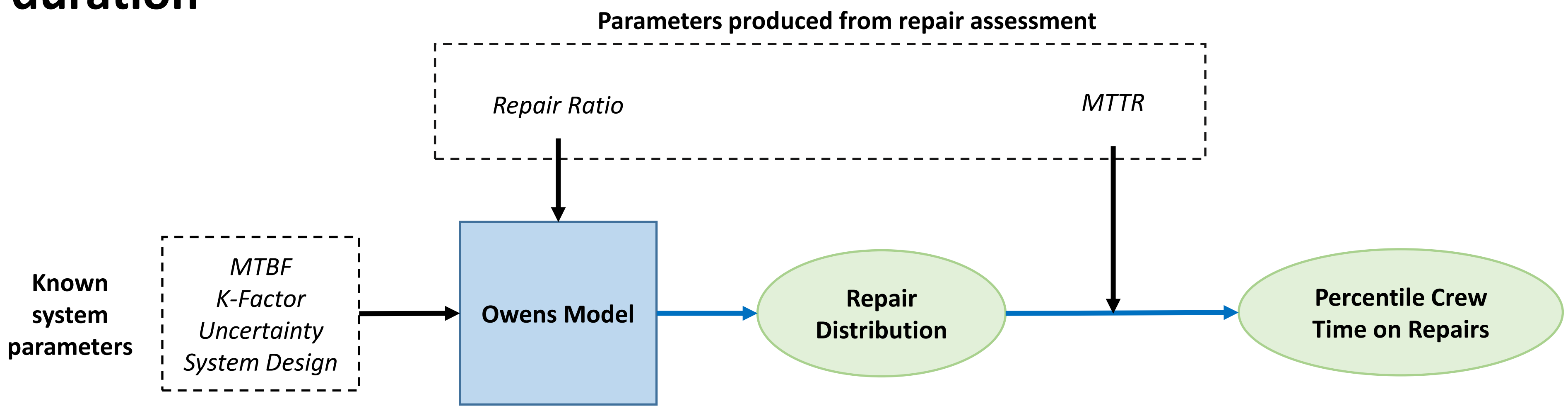
Component Categories	
1.	Air Valve
2.	Liquid Valve
3.	Air Component
4.	Liquid Component
5.	Complex Air Assembly
6.	Complex Liquid Assembly
7.	Electronics
8.	Pump
9.	Sensor
10.	Tank
11.	Fan
12.	Filters
13.	Reactor Assembly
14.	Heat Exchanger
15.	Plumbing
16.	External Components

Data Conditioning and Analysis

- **With the data separated and organized, two parameters are determined:**
  - Mean Time to Repair (MTTR)
    - The average crew-time to complete a non-R&R
    - Calculated for a component categories' failure type
  - Repair Ratio
    - The ratio of non-R&R actions to R&R actions
    - Defines the amount of repairs a component historically experienced per an R&R
- **The repair ratio is used to define the Mean Time Between Repairs (MTBR) when a component's Mean Time Between Failures (MTBF) and induced failure factor (K-Factor) are known**

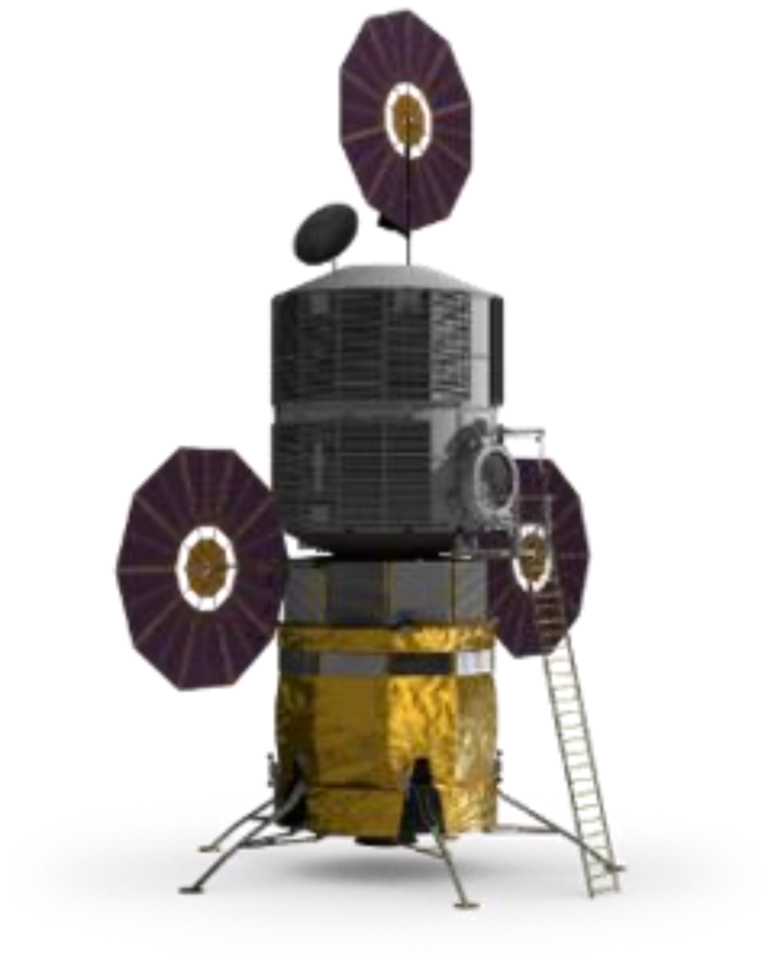
Maintenance Demand and Crew Time Model

- The Maintenance Demand Model and Crew Time Model (Owens) analyze the maintenance and repair requirements of spaceflight missions by producing probability distributions of required maintenance and repair actions and the associating crew time
- The model analyzes a set of ORU/components individually, determining repair distributions for each component
- The determined MTTR is applied to each repair distribution, producing a crew time distribution for each component
- The model results a probability distribution of total crew time required for repairs over a mission duration



Surface Habitat Case Study

- **This methodology was used to assess the corrective repair requirements of the planned Lunar Surface Habitat (SH)**
- **The SH is a proposed lunar surface element with life support systems capable of inhabiting crew members on the lunar surface for an extended duration**
- **A complete list of maintenance and repair components onboard the SH was created for analysis**
- **Parameters for this study:**
  - 2 crew members in SH for 28 days
  - Results are shown for nominal SH conditions



Surface Habitat Systems

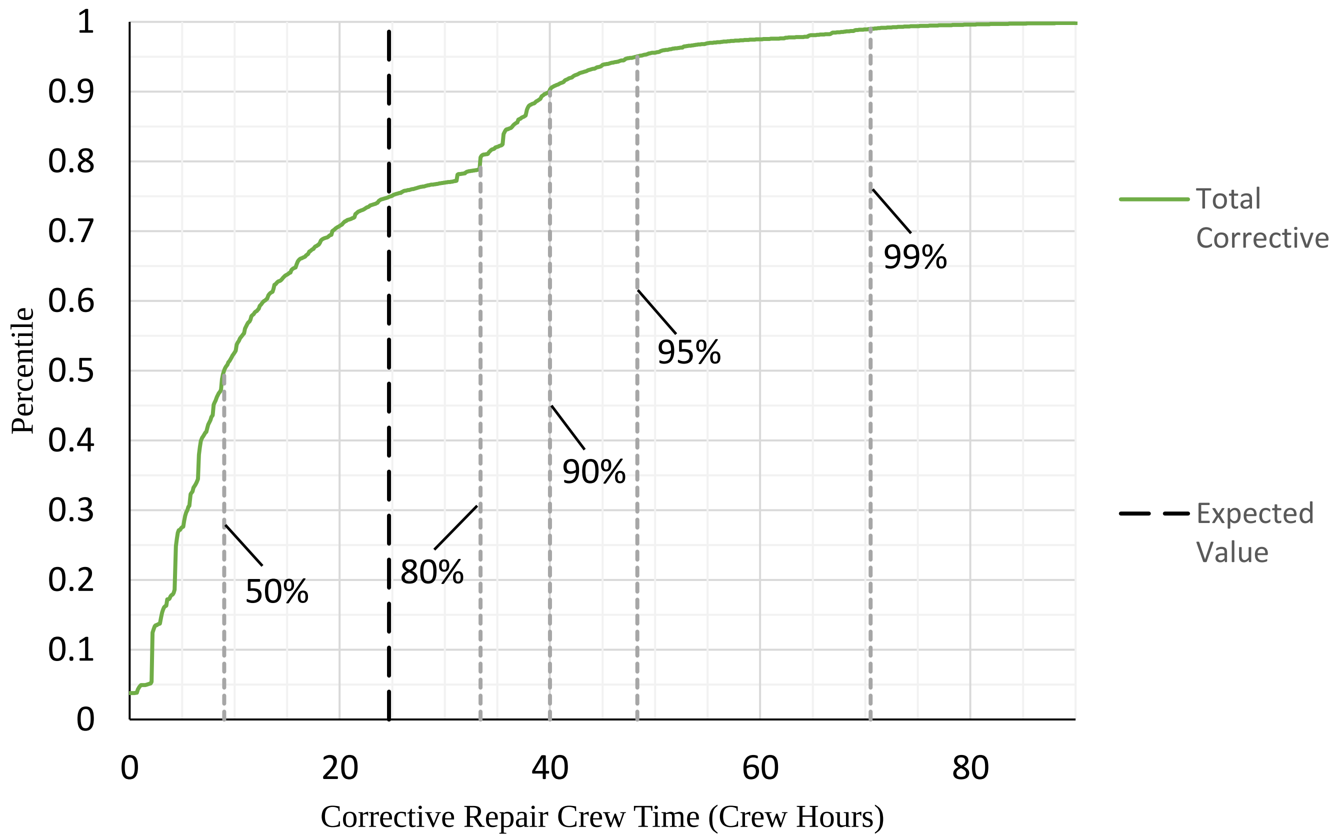
- For the corrective repair analysis, 17 SH systems were analyzed
- An important factor of predicting repair is the operating time of each subsystem
- Failure rates incorporate operating times, not total time
- Some systems need to operate 365 days a year to maintain SH health, while others only operate during crewed durations
- Failures can take place during uncrewed periods, requiring upfront repairs upon arrival

	System	Operating Days per Year
1.	Urine Processing (UPA)	28
2.	Water Processing (WPA)	28
3.	Brine Processing	28
4.	Pressure Control & Relief (PC&R)	28
5.	Air Circulation	28
6.	Air Temp. and Humidity Control (ATHC)	28
7.	Atmospheric Constituent Monitoring (ACM)	28
8.	Trace Contaminant Removal (TCCR)	28
9.	Oxygen Generation (OGA)	28
10.	High Pressure Oxygen Compressor (HPO_2)	28
11.	CO2 Removal	28
12.	CO2 Recovery	28
13.	Waste Management System (WMS)	28
14.	Electric and Power System (EPS)	365
15.	Communications and Tracking (C&T)	365
16.	Command & Data Handling (C&DH)	365
17.	Active Thermal Control (ATCS)	365

Corrective Repair Results

- The Crew Time Model produces a repair distribution of required crew time by percentile
- Increasing percentile from 50% to 99%, the required crew-time planned for repairs increases by 61.5 hours
- The crew time delta of this distribution is large, and is the largest scheduling variable in calculating possible science utilization time per mission

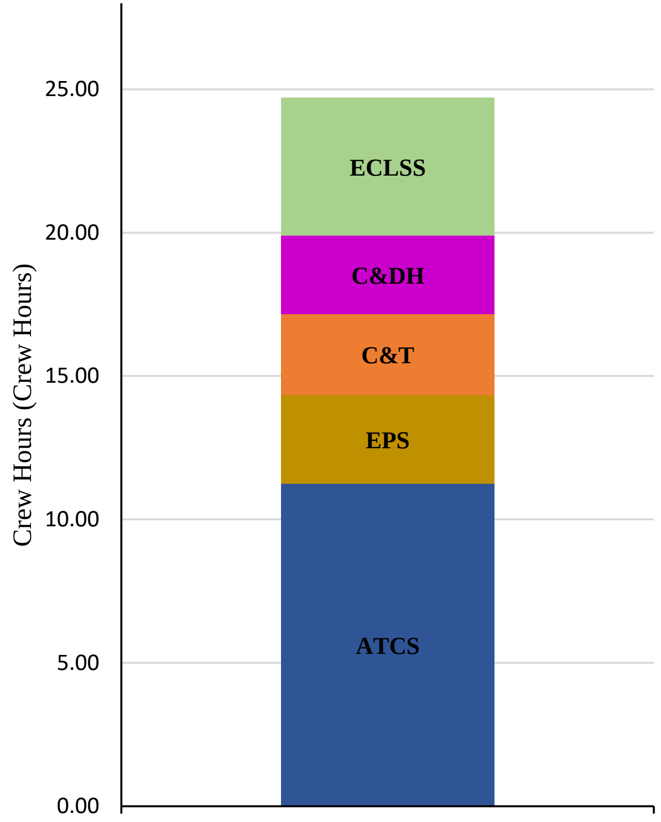
Percentile	Required Repair Time (hours)
50th	9.0
Expected Value	24.7
80th	33.4
90th	40.0
95th	48.3
99th	70.5



System and Component Based Results

- The results of the analysis can be further broken down by component category and system
- System and component results help predict corrective repair crew-time on future missions with varying system architecture

System	Total Expected Corrective Repair (hours)
Plumbing	2.21 E-03
Tank	0.01
Filter	0.06
Sensor	0.07
Air Component	0.10
Fan	0.11
Liquid Valve	0.17
Liquid Component	0.22
Reactor Assembly	0.41
Pump	0.44
Heat Exchanger	0.51
Complex Liquid Assembly	0.64
Air Valve	0.81
Complex Air Assembly	2.20
Electronics	6.43
External Components	12.52
TOTAL	**24.70**

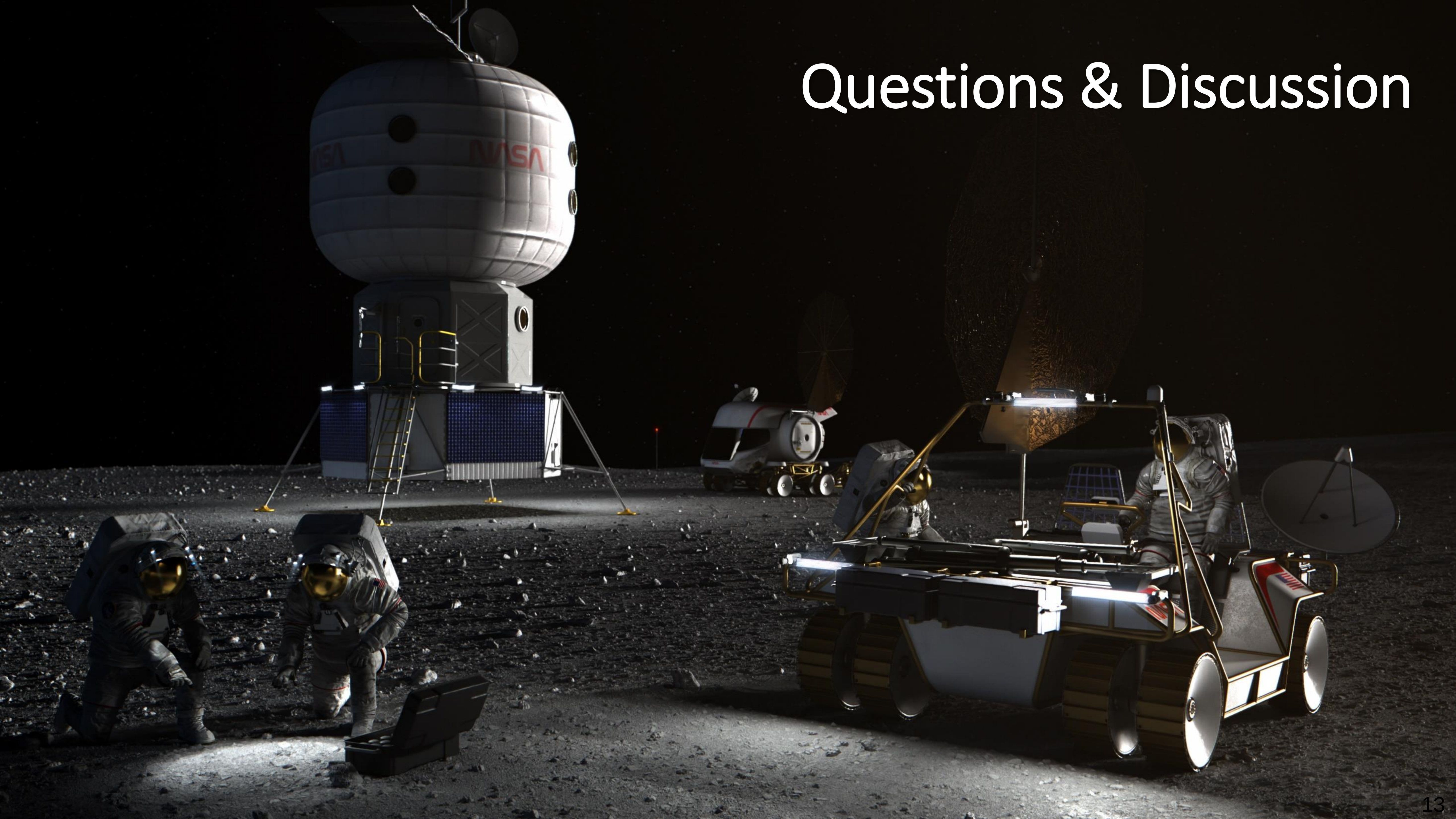


Conclusion and Future Work

- **Conclusion**
  - The authors have developed a new process to better predict maintenance and repair requirements for future missions
  - The methodology was applied to the sustained lunar surface mission in the Surface Habitat, which results are currently being applied to SH mission planning
  - A better understanding of required maintenance and repair during missions will aid in mission planning and likelihood of achieving mission objectives

- **Future Work**
  - Work with SME’s on developing efficient maintenance and repair plans for lunar surface missions
  - Applying the methodology presented to Mars based missions

Questions & Discussion



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Sources and Further Reading

- **On previous efforts and the Exploration Crew Time Model:**

  "Predicting Crew Time Allocations for Lunar Orbital missions based on Historical ISS Operational Activities"

  Stromgren, C., Escobar, F., Revadeneira, S., Cirillo, W., Goodliff, K.

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- **On the Maintenance Demand and Crew Time Model:**

  "Multiobjective Optimization of Crewed Spacecraft Supportability Strategies"

  Owens, A. C.

  Doctoral Thesis, Massachusetts Institute of Technology, 2019

  "How Much Testing is Needed to Manage Supportability Risks for Beyond-LEO Missions?"

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  49th International Conference on Environmental Systems, 7-11 July 2019, Boston, MA.

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